Nutritional Quality and Human Health Benefits of Important Cold-Water Fishes of the Indian Himalayas

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Prakash Sharma, Rini Joshi, Alexander Ciji, Md. Shahbaz Akhtar, and Debajit Sarma

Abstract

The world is still fighting to eradicate the problem of malnutrition on the one hand, and on the other, lifestyle diseases are growing alarmingly due to overnourishment with unhealthy food and a sedentary lifestyle. The world at present needs both nutritious and functional food to deal with this dual burden of nutrition. There is a need to expand the quality of food availability in every corner of the world. Over time, more health foods are being supplied to local and global food markets. Fish, among others on the list of nutritional and functional food, is a promising nutritional package that has a potential to reach the plate of every individual because of its diversity, variety, and wide range of affordability. Aquatic habitats of the Indian Himalaya harbor fishes of immense nutritional and functional value. Among these, *Tor* spp., *Neolissochilus* spp., *Schizothorax* spp., *Barilius* spp., *Crossocheilus* spp., and *Garra* spp., along with *Cyprinus carpio* and *Oncorhynchus mykiss*, are some of the important food fishes of the Indian subcontinental Himalaya. These fishes are a good source of protein, balanced amino acids, polyunsaturated fatty acids (eicosapentaenoic, docosahexaenoic, and arachidonic), and minerals (calcium, phosphorus, iron, copper, zinc, and manganese). Their overall nutrient richness contributes significantly to the daily requirements of humans of all ages, sex, and different physiological conditions.

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19.1 Introduction

Consumption of nutritionally deficient food due to unavailability or unaffordability, or the complete deprivation of food, and inadequacy of required nutrients for growth and development lead to malnutrition or malnourishment. Protein, energy, vitamin A, iron, and iodine deficiencies have been the leading cause of malnutrition-related health anomalies (WHO 2003). Prolonged malnourishment cases eventually lead to nutritional deficiency diseases (NDDs). NDDs are more prevalent in developing and underdeveloped nations of Asia, Africa, and South America. Globally, cases of undernourishment declined from 810.7 (12.4%) in 2005 to 615 million (8.1%) in 2017; however, instead of declining further, the cases started to increase after 2018 and reached 768 million (9.9%) in 2020 due to the global emergency, caused by the COVID-19 pandemic (FAO et al. 2021). Among these 768 million cases, the majority are from Asia (418 million), Africa (282 million), and Latin America, including the Caribbean (60 million), in descending order (FAO et al. 2021). The commonly reported signs of NDDs include growth retardation, developmental impairment (both physical and mental), compromised immunity, morbidity, and even mortality (Gragnolati et al. 2005).

On the one hand, some concerned global organizations are still struggling to bring down the cases of NDDs. And on the other, cases of lifestyle diseases (LDs), due to overnourishment and sedentary lifestyle, are rising globally. The main reasons behind the emerging and ever-increasing LDs include industrialization, globalization, global expansion of the food market, and consequently the polarization of packaged energy-dense food, sedentary working style, etc. (WHO 2003). The commonly reported LDs are obesity, diabetes, hypertension, cardiovascular diseases (CVDs), cancer, stroke, arthritis, osteoporosis, arteriosclerosis, sleep disorders, dementia, etc. (WHO 2003). Among these, CVDs, cancer of different types, chronic respiratory diseases, and diabetes are responsible for 82% of LD-related deaths (WHO 2014). Globally, cases of LDs are increasing year after year in an erratic fashion, affecting the global workforce, and had caused 38 million mortality in 2012, and the same is projected to reach 52 million by 2030 (WHO 2014).

Inappropriate food consumption, either due to unavailability of food or excessive intake from the prescribed limit, leads, respectively, to NDDs or LDs. Unhealthy eating habits involve eating unhealthy food, processed or energy-dense food, and nutritionally poor food. LD-related death can be avoided by including fruits, vegetables, whole grains, and lean meats, especially fish, in our diet in the correct proportion (Hasler 1998). With the rise of LDs, the concept of healthy food is becoming popular worldwide. The origin of the idea of healthy food is linked to the famous quote of Hippocrates, “Let thy food be thy medicine and thy medicine be thy food," given long back, i.e., around 400 BC (Witkamp and van Norren 2018). However, the world's first commercial functional food appeared very recently, i.e., during the mid of the 1980s, in the Japanese market (Hasler 1998). After that, the concept of evaluating the potential food materials for their nutritional and functional quality became popular. Worldwide, all possible food materials, from vegetables, spices, and herbs to animals, especially fishes, are being evaluated for their nutritional and functional quality (Rayner et al. 2004). Based on these evaluations and the presence of any bioactive compounds, foods are being included in the functional category.

Information on the nutrient composition of native fishes from every possible corner of the world are being recorded. As a consequence, more and more food fishes are merging into the global food market. Similarly, the nutritional compositions of the Indian subcontinental fishes are also being evaluated, and a good body of nutritional information is developed (Bogard et al. 2015; Joshi et al. 2017, 2018; Joshi 2017; Mohanty et al. 2014, 2016a, b; Sarma et al. 2013, 2014, 2019, 2022). The nutrient profiling of Indian fishes was started long back, initiated by Saha and Ghosh (1938–1939, 1939–1940, 1941). Again, after three to four decades, some more nutrient information on Indian fishes came to light, authored by Sen et al. (1977), Nair and Gopakumar (1977, 1978), Lilabati and Viswanath (1996), Ghosh and Dua (1997), and others. Realizing the importance of nutritional and functional information of food fishes, the Indian Council of Agricultural research (ICAR) started a nationwide fish nutrient profiling program to generate compositional information of possibly all Indian fishes. In this process, some more nutrient profile data of Indian fishes came into the picture (Joshi 2017; Joshi et al. 2017, 2018; Sarma et al. 2013, 2014, 2019, 2022; Mohanty et al. 2014, 2016a, b).

Indian Himalayan cyprinids (IHCs) contribute to a large extent to Himalayan fisheries (Joshi et al. 2017). Out of the several such IHCs, partial nutritional information is available for *Tor putitora*, *Neolissochilus hexagonolepis*, *Labeo dero*, *L. dyocheilus*, *L. pangusia* (Sarma et al. 2013, 2014; Mohanty et al. 2014, 2016a, b); *Schizothorax curvifrons*, *S. esocinus*, *S. labiatus*, *S. niger*, *S. progastus*, *S. plagiostomus*, and *S. richardsonii* (Joshi 2017; Joshi et al. 2017, 2018); and *Barilius bendelisis*, *Garra lamta*, and *Crossocheilus latius* (Sharma et al. 2020; Sharma and Singh 2020). These fishes are distributed in the Indian cold-water habitats from Jammu and Kashmir to Arunachal Pradesh, contributing a considerable share to the local fishery of Himalayan belts (Singh and Akhtar 2015). These sources of information on the nutrient composition of Indian subcontinental Himalayan fishes are scattered in different forms, such as research articles, dissertation documents, books, bulletins, etc.; if it is made available on a single platform, they form a valuable database. In this chapter, the authors have attempted to compile the scattered nutritional and functional information of these fishes as a single document for better understanding.

19.2 Fish as a Functional Food

Among the long list of functional foods, fish has a long history of protecting humans from many diseases and death (Lund 2013). Fish as functional food was known from the evidence of reduced cardiovascular illness-related mortality among Eskimos on fish consumption (Lancet 1983). Fish is consumed by people, irrespective of whether they are rich or poor, young or old, healthy or unhealthy. Some prefer to eat for its delicacy, while others may eat for its availability, affordability, functionality, or richness in nutrient contents (Lund 2013; Kawarazuka 2010). Depending on species, their habitat, and food and feeding habits, different fishes have different nutrient and nutraceutical compositions (Kawarazuka 2010).

Fish is a functional food for its superior oil and fatty acids composition. However, it not only contains long-chain n-3 polyunsaturated fatty (n-3 LC-PUFAs; eicosapentaenoic acid, EPA; and docosahexaenoic acid, DHA) acids, but it also is a source of other healthful nutraceuticals like vitamin A, D, B12, selenium, iodine, iron, zinc, choline, and taurine (see Fig. 19.1; Lund 2009). Therefore, the habit of fish eating is a healthy practice. This healthy eating habit can protect us against cardiovascular diseases (CVDs) (Leaf and Webber 1988), atherosclerosis, arrhythmia (Givens et al. 2006), thrombosis (Harris 2004), inflammation (Simopoulos 2002), rheumatoid arthritis (Berbert et al. 2005), and depression (Horrobin and

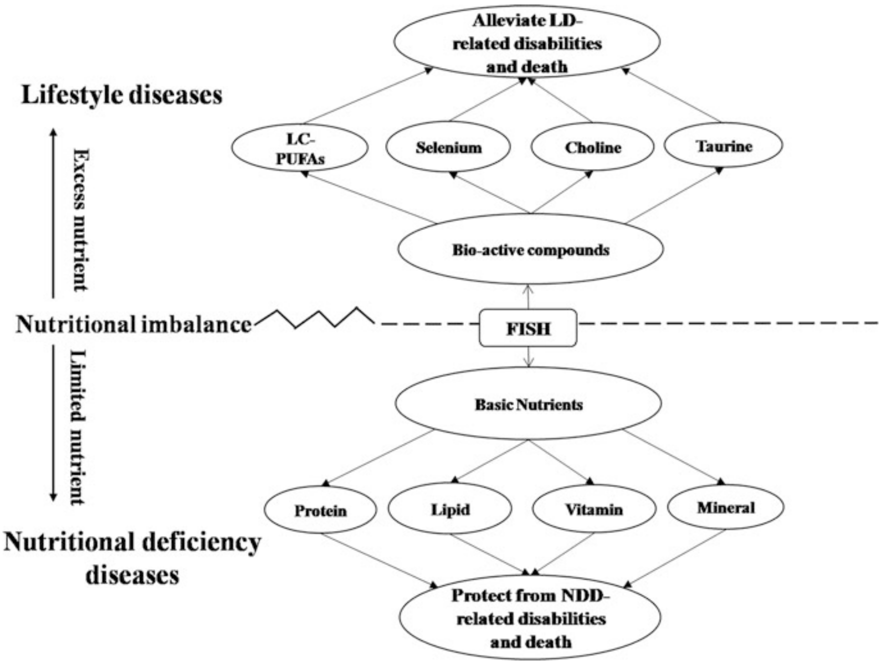

Fig. 19.1 Illustration of the nutritional and functional potential of fish for reducing the double burden of nutritional imbalance

Bennett 1999). Due to their superior nutrient composition, especially, the easily digestible protein, balanced amino acids (particularly the essential ones, EAAs), oil, fatty acids, and other bioactive components like taurine, choline, vitamins, and minerals, they are considered as functional food with dual potential to fight the evils of neurodegenerative diseases (NDDs) and lifestyle diseases (LDs).

The preference for fish over other animal proteins is growing among health-conscious elites in urban communities. Consequently, the proportion of the fish-eating population and per capita consumption are increasing year after year (FAO 2022). The global per capita fish consumption has increased from 15.7 in 2006 to 17.2 kg/person/year in 2010 (World Bank 2013) and 20.5 kg/person/year in 2019 (FAO 2022). Because of the variety of nutrients and nutraceutical content, fish cannot be replaced with other animal meat (Gogus and Smith 2010). Even vegetable oil, like linseed, sunflower, and soybean oil, cannot substitute fish oil, although they contain higher levels of n-3 and n-6 PUFAs, because no other oil is as superior as fish oil, in terms of EPA and DHA content (Burdge and Calder 2005). Rather than consuming individual concentrated nutraceuticals, which may prove harmful, eating fish as a whole is always beneficial because essential nutrients and nutraceuticals are retained in a diluted form, which are slowly released in the gastrointestinal tract during digestion (Gormley 2006). Depending on the flavor and functionality of fish, the price and demand are adjusted with maximum possible margins, favorable for the producers and retailers. For this delicate balance of preference, demand, and supply, fish has become affordable for all classes of the population.

Depending on the species (genetic lineage), habitat (marine or freshwater), and habitat-linked food and feeding habit, they show differences in nutrient compositions and functionality (Grigorakis 2007). Some fishes are lean, while others are fatty; some are good in taste and flavor, and some have medicinal values. For example, marine fatty fish have more lipid and higher levels of n-3 LC-PUFAs than freshwater fish (Ackman 2002). Because of this diversity, availability, and species-specific uniqueness in nutrient content and flavor of fishes, consumers can make healthful choices depending on their preference and price with a higher degree of freedom. The nutritional and functional attributes of fishes vary from species to species; therefore, evaluating the nutraceuticals and nutrient composition of all edible fish is essential to rank them on their nutritional and functionality values.

19.3 An Overview of the Nutritional Composition of Fish

The primary nutrient compositional information is based on an estimated four major components of fish, namely, moisture, protein, oil, and ash (minerals) (Joshi 2017). Since fish is the source of protein and oil, and carbohydrate and fiber contents are negligible, therefore, their estimation is not essential (Shearer 1994). Biochemical composition not only varies at family and genera but also at species level (Shearer 1994). Therefore, the nutrient composition of fishes is species-specific and depends on their food and feeding habits. Each fish is unique in morphology, morphology-driven locomotion, food-acquiring mechanism, food and feeding habit, niche, and habitat preferences. Due to this complexity in the interaction of these morphological, physiological, and ecophysiological variations, they exhibit a similarly higher degree of heterogeneity in nutrient composition. The nutrient and nutraceutical contents of a species cannot be taken for generalizing the same of other species of the family. Therefore, evaluating the same in all edible fish species is essential to assess their nutrient content and contribution potential.

In nature, the food and feeding of fish change with their own physiological rhythm and the ecological dynamics of their living environment (Joshi 2017). The cyclic physiological rhythm brought by the reproductive cycle, pre-spawning gonadal development, spawning, post-spawning recovery, etc. brings corresponding changes in biochemical composition (Sharma et al. 2021). Similarly, ecological dynamics brought by the seasonality of natural food abundance also contribute to the seasonal nutrient dynamics (Joshi 2017). In natural habitats, seasonal feeding restriction due to unavailability results in depletion of protein and lipid, in general (Wang et al. 2006). Otherwise, the reports on micronutrient dynamics in such a situation are rarely reported in fish. During the post-spawning and consequent intense feeding, nutrients are recovered first to compensate for the loss. Eventually, the nutrients are accumulated over time to form a reserve for the subsequent gonadal development or the next migration event (Hatch 2012). The lipid dynamics and corresponding fatty acid changes are studied deliberately in fishes, than the protein and amino acids. Although the level of protein as well changes in some situations, this change is being overlooked.

Within the species, increase in fish size with aging also brings compositional dynamics; lipid content of fish increases with an increase in weight, due to their accumulation in the muscle, subcutaneous tissue, and peritoneal cavity, and this leads to decreases in protein and minerals (Brown and Murphy 1991; Martinez et al. 1992). Similarly, protein content increases with a growth-related increase in fish size (Grigorakis et al. 2002; Kim and Kaushik 1992; Weatherley and Gill 1983). Information on weight-dependent lipid accumulation in fishes is consistent (Fig. 19.2). However, the information on size-dependent protein content is not. Some investigators have reported the protein increase to a certain size during early growth (Grigorakis et al. 2002) or until fingerling (Weatherley and Gill 1983), or throughout life (Kim and Kaushik 1992). Contrarily, others have reported the decrease in protein with the growth or aging of fish (Martinez et al. 1992).

Even the biochemical composition, especially the lipid content, of muscle from different parts of a fish is also not the same; the ventral muscle is more rich in oil than the dorsal (Aursand et al. 1994; Kinsella et al. 1977; Zhou et al. 1996). Similarly, head and anterior muscle have more oil than the posterior and peduncular muscle (Austreng and Krogdahl 1987; Kinsella et al. 1977; Stansby 1973). Oil content differs with the muscle type in a steak of the same part; the red muscle contains more oil and less protein (Austreng and Krogdahl 1987; Kiessling et al. 1989; Ingemansson et al. 1991).

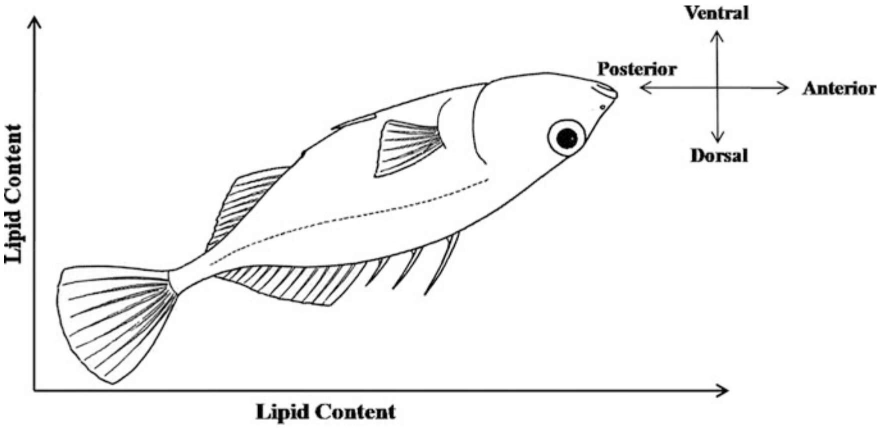

Fig. 19.2 Lipid distribution in fish body

19.4 Fish as a Source of Protein

Fish protein is considered the best among animal proteins for consumption due to its high digestibility and amino acid composition. Out of the total muscle proteins, structural (actin, myosin, tropomyosin, and actomyosin), sarcoplasmic (albumin, myoalbumin, globulin, etc.), and connective tissue proteins (collagen, elastin, etc.) contribute to 70–80%, 25–30%, and 3–5%, respectively, in fishes (Joshi 2017; Ryu et al. 2021). Otherwise, the respective protein compositions in mammals are 40%, 35–40%, and 15–20% (Joshi 2017). The comparatively higher muscle protein (structural) and lesser connective tissue protein in fish, than in mammals, make the fish meat easily digestible compared to that of mammals (Jacquot 1961).

The nutritional quality of meat is evaluated based on the absolute value of protein content and its digestibility, its amino acid composition (especially the essential amino acids; EAA), and the bioavailability of amino acids upon digestion. Fish protein contains all the EAAs and, like milk, eggs and most of the edible mammalian meat protein. Based on evaluation criteria like chemical or amino acid score, biological value, and protein efficiency ratio, fish protein is superior to milk, beef, pork, and chicken (Sheeshka and Murkin 2002). The chemical score of fish muscle (70) is better compared to beef (69) and milk (60) (Sheeshka and Murkin 2002). Similarly, the biological value (76%) is higher than that of beef (74.3%), pork (74.0%), and chicken (74.3%) (Sheeshka and Murkin 2002).

Among the Indian cold-water fishes, information on protein content is available for *C. carpio* (collected from the Himalayan region), *O. mykiss*, *N. hexagonolepis*, *T. putitora*, *S. curvifrons*, *S. esocinus*, *S. labiatus*, *S. niger*, *S. plagiostomus*, *S. progastus*, *S. richardsonii*, *B. bendelisis*, *C. latius*, and *G. lamta* (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2014; Sarma et al. 2013, 2022; Sharma et al. 2020; Sharma and Singh 2020). The protein content and their contribution potential (daily

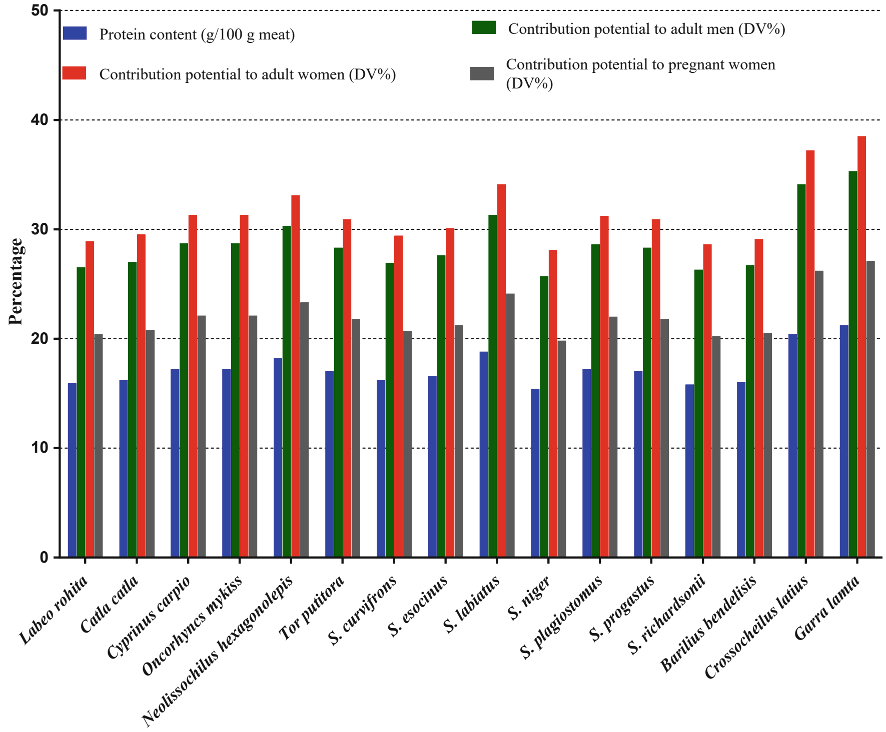

Fig. 19.3 Protein content (mg/100 g) of some common tropical edible carps and cold-water fishes from Indian Himalaya and their daily value (DV%) percentage to meet the daily protein requirement of adult men, women, and pregnant women (DV% calculated based on RDA recommended by ICMR 2010). The data are compiled from published reports (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2014; Sarma et al. 2013, 2022; Sharma et al. 2020; Sharma and Singh 2020)

value percentage; DV%) to recommended dietary allowance (RDA) to a human at different physiological stages of cold-water fishes are summarized and presented in Fig. 19.3, along with those from common edible IMCs (*L. rohita* and *C. catla*). The protein contents of some of the cold-water fishes are significantly higher (>18%) than those of tropical IMCs (16%); these include *G. lamta*, *C. latius*, *S. labiatus*, and *N. hexagonolepis* (Joshi 2017; Mohanty et al. 2014; Sarma et al. 2022). Other fishes with moderately higher protein (17%) content include *O. mykiss*, *C. Carpio*, *T. putitora*, *S. plagiostomus*, and *S. progastus* (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2014; Sarma et al. 2022). According to these reports, these fishes were collected for evaluation, from different locations in the western and central Himalayan region, but the reported protein content is independent of the collection site (Joshi 2017; Sarma et al. 2022). The local biotic and abiotic factors and region-specific feeding did not alter the protein composition.

19.5 Dietary Protein Contribution Potential

Protein is adequately required in the human diet to maintain healthy growth and functioning. The requirement varies with developmental stages and physiological conditions. Protein requirement is critically higher in pregnant and lactating women, as additional protein is required for the growth and development of the fetus and newborn. Otherwise, in the adult stage, it is needed only for compensating the wear and tear of body protein, not for growth. Human dietary protein requirements are fixed, based on methods such as nitrogen balance (widely used and most recommended), nitrogen losses, and protein utilization efficiency (ICMR 2010).

ICMR (2010) has recommended the daily protein requirements for adult men and adult, pregnant, and lactating women, specifically for the Indian population, as 60, 55, 78, and 74 g/day, respectively. Based on these RDA data and protein contents of evaluated Indian Himalayan fishes, the calculated DV% [(protein available per gram of meat/RDA) × 100] is significantly higher in *G. lamta* and *C. latius* and moderately high (higher than IMCs) in *S. labiatus*, *N. hexagonolepis*, *O. mykiss*, *C. Carpio*, *T. putitora*, *S. plagiostomus*, and *S. progastus*. In India, nearly 46% of preschool children and around 30% of adults suffer from malnutrition with different levels of severity, i.e., moderate to severe (ICMR 2010). The problem of malnutrition exists in pockets of the country where people cannot afford to buy sufficient food or nutritional food and food items rich in protein are expensive compared to those rich in carbohydrates. These protein-rich Himalayan fishes may help fight against the existing remains of malnutrition in the Indian subcontinental Himalaya.

19.6 Amino Acid Composition of Fish

Amino acids are the basic units of macromolecular protein of all different types and functions. Additionally, some of the amino acids serve as either substrate or intermediates in various metabolic pathways for the synthesis of physiologically important biomolecules such as nucleotides, hormones, neurotransmitters, polyamines, glutathione, creatine, carnitine, carnosine, thyroid hormones, serotonin, melanin, melatonin, heme, etc. (Blachier et al. 2011; Kong et al. 2012; Wu 2009). Therefore, they are essential in the diet, and most of them are served in the form of dietary protein. The requirements of dietary amino acids vary depending on developmental stage, physiological status, gut microflora, environmental factors, and the pathological condition of the individual (Dai et al. 2011, 2012a, b; Wu et al. 2013).

Along with protein, fish is a good source of a balanced composition of EAAs and NEAAs (Bruke et al. 1997; Buttery and D'Mello 1994; Dahhar and Elshazly 1993). Each fish has unique amino acid compositions depending on its species-specific food and feeding habits (Grigorakis 2007). The compositional uniqueness of amino acids not only depends on genetic lineage, but it also varies within the species depending on their distribution, size, sex and sexual maturity, environment, and food availability (Ozyurt and Polat 2006). The annual gonadal cycle is a significant intrinsic feature that brings seasonality to the amino acid composition (Duyar 2000).

Table 19.1 Essential amino acid composition (g/100 g protein) of some common Indian tropical carps and Indian Himalayan cold-water fishes (captured from wild)

Amino acids (g/100 g protein)	Met	Arg	Trp	Thr	Val	Ile	Lys	Leu	Phe	His
Labeo rohita	2	1	1	6	6	6	3	9	6	4
Catla catla	2	2	1	6	7	6	4	8	5	5
Cyprinus carpio	1	2	1	1	1	1	1	2	1	<1
Oncorhynchus mykiss	3	7	6	6	5	7	4	6	3	1
Neolissochilus hexagonolepis	1	2	<1	1	2	1	2	2	1	1
Tor putitora	4	4	7	4	4	4	9	8	6	1
Schizothorax curvifrons	1	4	–	3	5	5	2	10	7	1
S. esocinus	2	5	–	4	5	6	2	13	12	2
S. labiatus	3	5	–	6	7	10	4	21	17	2
S. niger	2	6	–	5	6	7	2	15	13	2
S. plagiostomus	2	5	–	4	5	6	3	12	10	2
S. progastus	3	6	–	6	7	7	2	16	13	7
S. richardsonii	4	6	–	5	7	8	4	18	11	2

The mean values only are presented here from different sources (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2014; Sarma et al. 2013, 2022)

Among the Indian cold-water fishes, information on amino acids content is available for *C. carpio* (collected from the Himalayan region), *O. mykiss*, *N. hexagonolepis*, *T. putitora*, *S. curvifrons*, *S. esocinus*, *S. labiatus*, *S. niger*, *S. plagiostomus*, *S. progastus*, *and S. richardsonii* (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2014; Sarma et al. 2013, 2022). The EAA compositions of cold-water fishes are summarized from these published sources of literature and are present in Table 19.1, along with the composition from common edible IMCs (*L. rohita* and *C. catla*). The most abundant amino acids are glutamic and aspartic acid (Joshi 2017; Sarma et al. 2022). After analyzing the EAA abundance pattern from Table 19.1, the following compositional conclusion is drawn. *T. putitora*, *S. richardsonii*, *O. mykiss*, *S. labiatus* and *S. progastus* are rich in methionine (3–4 g/100 g protein). *O. mykiss*, *S. niger*, *S. progastus*, *S. richardsonii*, *S. esocinus*, *S. labiatus* and *S. plagiostomus* are rich in arginine (more than 5 g/100 g protein). *O. mykiss* and *T. putitora* are rich in tryptophan (6 g/100 g protein).

Threonine, valine, isoleucine, and lysine are poor (around 1 g/100 g protein) in *C. carpio* and *N. hexagonolepis*; otherwise, most of the evaluated species are comparatively rich in these EAAs as *L. rohita* and *C. catla* do. Isoleucine has a vital role in growth, muscle formation (Charlton 2006), and renal function (Vuzelov et al. 1999). Similarly, leucine and phenylalanine are rich in most of the evaluated *Schizothorax* spp. (more than 10 g/100 g protein). Leucine has several physiological importance, such as the induction of muscle protein synthesis (Etzel 2004) and reduction of stress conditions such as trauma, burn, sepsis, etc. (De Bandt and Cynober 2006). Similarly, phenylalanine has an important role in immunity (Wu and Meininger 2002), neurotransmission (through epinephrine, norepinephrine, and dopamine; Malinski

2000), regulation of blood pressure (Malinski 2000), regulation of metabolism (through thyroid hormone synthesis; Kim et al. 2007), etc. The only cold-water species rich in histidine (compared to *L. rohita* and *C. catla)* is *S. progastus*. Otherwise, most of the other cold-water species are poor in histidine content.

19.7 Amino Acid Score

Apart from amino acid composition, the protein quality is graded by amino acid score (AAS). Among many forms of protein quality testing tools and parameters, such as protein efficiency ratio, net protein utilization, and biological value (where in all these cases animals for bioassay are needed), the AAS method is easy, efficient, and best for qualifying and ranking EAAs (FAO-WHO 1990). Generally, AAS is done for preschool children, because they need more EAAs in their diet, i.e., 30% of dietary protein, but in adults, it is just 15% of dietary protein. Scoring evaluation done with preschool children gives extra margin for adults. The calculated AAS values of all evaluated cold-water species are presented in Fig. 19.4, along with the values of *L. rohita* and *C. catla*. Among all evaluated cold-water fishes, *C. carpio* and *N. hexagonolepis* have low AAS values for most essential amino acids. Otherwise, most of the *Schizothorax* spp. have a comparatively better AAS value. Further, among all evaluated Indian Himalayan *Schizothorax* spp., *S. labiatus* has the best combination of AAS values (Joshi 2017; Sarma et al. 2022).

19.8 Fish Oil

Generally, oil or fat refers to triglyceride, while lipid refers to triglyceride and phospholipids (polar fraction) (Ackman 1967). Lipid is the fraction of fish extracted by organic solvents (Brianna and Brian 2006). In the current context, the authors are using the term oil instead of lipid, as oil is standard in human nutrition, and it matches with the scope of this chapter. The fish oil contains phospholipids and triglycerides; the phospholipid forms an integral part of the cell membrane, called structural lipid, while the triglyceride is the storage form of lipid, and it is called depot fat (Ackman 1967). Abundantly oil-containing fish tissues have a higher TAG proportion than tissues deficient in oil; otherwise, in low oil-containing tissues, PLs are abundant (Linder et al. 2010). Phospholipids are the functional constituents of biological membranes, and they contain more PUFAs (up to 58%), with proportionately more DHA than other fatty acids (Henderson and Tocher 1987). In IMCs, compared to muscle, the liver contains more oil (Ackman 2002).

Oil is distributed in various locations of the fish body, such as the liver, muscle, and peritoneal cavity along with viscera, head (abundantly in brain and eyes), and to some extent in gills, skin, bone, and gonad (Henderson and Tocher 1987). Depending on the oil content, Ackman (1967) classified fishes into different categories like lean (<2% fat), low fat (2–4% fat), medium fat (4–8% fat), and high fat (>8% fat). Generally, in lean fishes, the liver contains more oil, while in

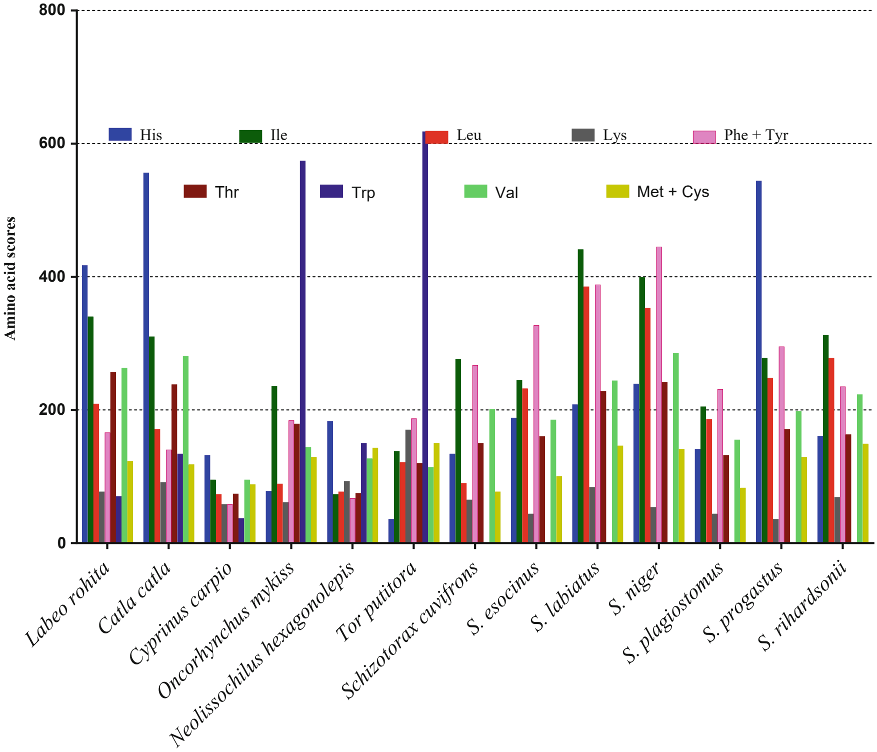

Fig. 19.4 Amino acid scores of cold-water fishes from Indian subcontinental Himalayas and of *Labeo rohita* and *Catla catla*. The AAS calculation is based on the EAA requirement for the preschool children (2–5 years). The mean values only are presented here from different sources (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2014; Sarma et al. 2013, 2022)

fatty fishes, the muscle and peritoneal cavity contain more (Ackman 1967; Cowey 1993).

Based on this classification, *L. rohita* and *C. catla* are low-fat-containing fishes (Mohanty et al. 2016a). Among cold-water species, *S. progastus* and *S. richardsonii* are lean fishes. *C. carpio*, *O. mykiss*, *N. hexagonolepis*, *S. plagiostomus*, *C. latius*, and *G. lamta* are low-fat-containing fishes, while *T. putitora*, *S. curvifrons*, *S. esocinus*, *S. labiatus*, *S. niger*, and *B. bendelisis* are medium-fat-containing fishes. None of the Indian cold-water fishes, evaluated for nutritional composition, is found to fall in the category of fatty fishes. As none of these fishes contain oil above 8 g/ 100 g muscle tissue, similarly, their contribution potentials to meet the RDA for moderately working adult men and women are also negligible (Fig. 19.5).

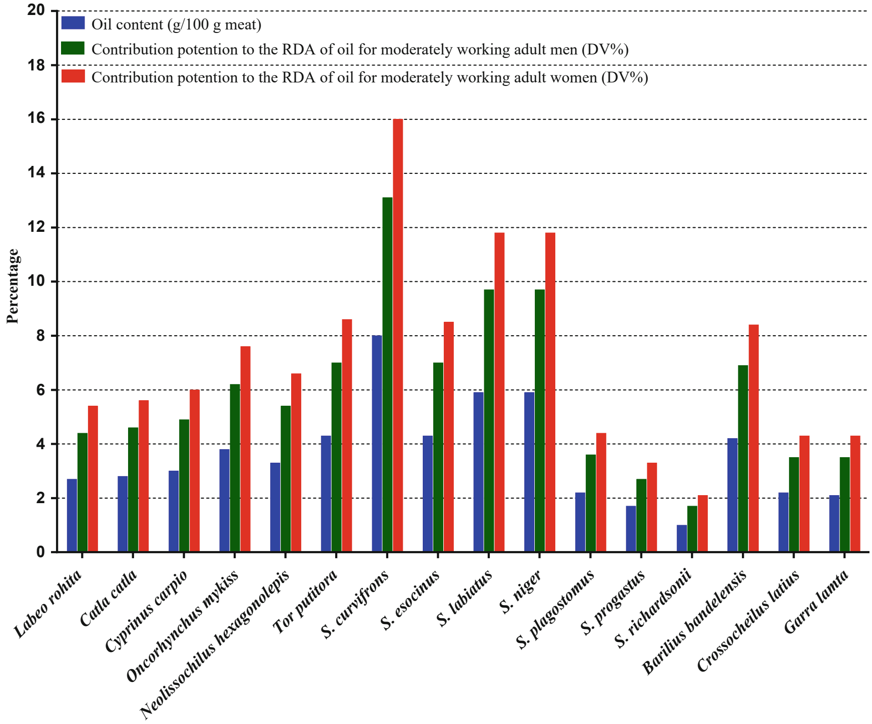

Fig. 19.5 Oil content (mg/100 g) of some common tropical edible carps and cold-water fishes from Indian Himalaya and their daily value percentage to meet the daily oil requirement of moderately working adult men and women (DV% calculated based on RDA calculated in the box below. The data are compiled from published reports) (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2016a; Sarma et al. 2013, 2022)

Calculation for recommended dietary allowance (RDA) of fat

RDA value of dietary fat, for adult male and female, according to ICMR (2010) is 20% of the total energy intake per day.
The total energy requirement of moderately a working man is 2730 kcal/day (ICMR, 2010)
The total energy requirement of moderately a working woman is 2230 kcal/day (ICMR, 2010)
The energy requirement from dietary fat for a man = (20 × 2730)/100 kcal/day=546 kcal/day
The energy requirement from dietary fat for a woman = (20 × 2730)/100 kcal/day=446 kcal/day
A gram of dietary fat on oxidation yield 9 Kcal energy.
In other way round, for getting 9 Kcal energy, 1 g of dietary fat is required.
For getting 1 Kcal energy, 1/9 g of dietary fat is required.
For getting 546 Kcal energy, (1/9) × 546 (i.e., 60.67) g of dietary fat is required.
For getting 546 Kcal energy, (1/9) × 446 (i.e., 49.55) g of dietary fat is required.

After rounding off the figures, it can be stated that:
The dietary fat requirement per day for a moderately working man is = 61 g/day
The dietary fat requirement per day for a moderately working woman is = 50 g/day

19.9 Fatty Acid Composition of Fishes

Fatty acids are crucial nutrients for all animals, including humans, and oil is the only source of these nutrients as the constituents, along with glycerol. They are sources of energy like carbohydrates but yield ATP through a different pathway called β-oxidation. Fatty acids serve as precursors of several bioactive compounds; some have structural and functional roles in cell membranes. Fatty acids have 4–24 (C4 to C24) aliphatic carbon chains, with a carboxylic acid group at the end. They can be either saturated or unsaturated, depending, respectively, on the absence or presence of double bonds.

Further, depending on the number of double bonds, they are classified as monounsaturated (MUFAs; monoene; one double bond in a chain), PUFAs (diene or triene; 2–3 double bonds in a chain), and LC-PUFAs (carbon chain 20–24 with 4–6 double bonds). Among PUFAs and LC-PUFAs, depending on the position of double bonds from the methyl terminal, they are classified either as n-3 or n-6 FAs. Some common n-3 PUFAs include α-linolenic acid (ALA; C18:3n-3), stearidonic acid (SDA, C18:4n-3), and n-3 LC-PUFAs which include EPA and DHA, while n-6 PUFAs include linoleic acid (C18:2n-6; LA), and n-6 LC-PUFAs include arachidonic acid (C20:4n-6, ARA). Animals, including fish to humans, cannot convert saturated and monounsaturated fatty acids to LA and ALA; therefore, their inclusion in the diet is indispensable. Therefore, LA and ALA are essential fatty acids (EFA; Tocher 2003). However, they (including fish) can bioconvert these EFAs to C20 and C22 LC-PUFAs like ARA, EPA, DPA, and DHA (Tocher 2003).

19.10 Habitat and Food-Dependent Fatty Acid Dynamics in Fishes

The ability of fish to elongate and desaturate LA and ALA to respective LC-PUFAs depends on the abundance and activities of elongases and desaturases (especially Δ6 and Δ5) and the availability of precursor and product fatty acids in their diet or natural food (Tocher 2003). The ability of marine fish to convert LA and ALA to LC-PUFAs is limited; however, freshwater counterparts are comparatively more efficient because LC-PUFAs in freshwater habitats are less prevalent than in marine (Tocher 2003, 2010). This ability in freshwater fishes through evolution is enhanced by nutritional discrepancy (Castro et al. 2012; Tocher 2010). Therefore, compared to marine, freshwater fishes are rich in C16 and C18 fatty acids, LA, γ-linolenic acid (GLA; C18:3-n-6), ALA, and AA but poor in EPA, DPA, and DHA (Ackman 1967; Lovern 1942, 1964; Ackman and Eaton 1966; Ackman 1967; Ozogul and Ozogul 2007; Ozogul et al. 2008). The fatty acid composition of fish muscle depends on food and feeding habit. For example, algae and phytoplankton-eating fishes (herbivores) are rich in both LA and ALA (Henderson and Tocher 1987; Brown et al. 1989). In contrast, zooplankton and prey fish-eating fishes are rich in n-3 LC PUFAs but poor in LA and AA (Brown et al. 1989).

The fatty acid composition also varies within the same species, depending on whether the fish is wild-caught or farm-reared. Fish caught from wild have different fatty acid profiles compared to farmed fish (Grigorakis 2007; Alasalvar et al. 2002; Grigorakis et al. 2002; Saglik et al. 2003; Mnari et al. 2007). Generally, cold-water fishes are known to have more n-3 LC PUFAs compared to warm-water counterparts and vice versa, because low temperature triggers the desaturation of membrane lipids to maintain flexibility and permeability of cells (Henderson and Tocher 1987; Lovell 1991).

19.11 Seasonal Variation of Fatty Acids

Fatty acid composition in fish flesh also changes with the change in season, and this is mainly due to gonadal cycling; seasonal change in environmental conditions like temperature, salinity, etc.; seasonal dynamics of natural fish food abundance; and their respective changes in fatty acid (Bandarra et al. 2001; Gökçe et al. 2004). There are many reports on seasonal changes in fatty acid profile of fishes of both marine (*Trachurus trachurus*, *Engraulis encrasicolus*, *Sardina pilchardus*, *Sprattus sprattus*, *Solea solea*, *Spicara smaris*) and freshwater (*Sander lucioperca*, *Carassius auratus*, *Colossoma macropomum*, *Leporinus friderici*, *Prochilodus nigricans*, *Brachyplatystoma filamentosum*, *Brachyplatystoma flavicans*, *Thymallus arcticus*) groups (Pirini et al. 2010; Gökçe et al. 2004; Zlatanos and Laskaridis 2007; Guler et al. 2007; Dal Bosco et al. 2012; Petenuci et al. 2016; Sushchik et al. 2007).

In most of these reports, information on sex-specific seasonal fatty acid dynamics is missing, because in their analysis, male and female fishes were not separated and their gonadal status was also not taken into account. Otherwise, fatty acids, like other macronutrients such as protein and lipid, get partitioned from the muscle toward the gonad, especially at depending phases of the gonadal cycle for the development and maturation of testis and ovary (Johnson et al. 2017).

The seasonal muscle fatty acid dynamics due to changing gonadal status is stronger in females than males because of the vitellogenesis and yolk formation. In this process, a significant proportion of lipid and FAs get partitioned from different parts of the body toward the gonad for gonadal development (Sharma et al. 2021; Cejas et al. 2004). In a seasonal fatty acid partitioning study conducted in *T. putitora*, from wild lacustrine habitat, gonadal seasonality-dependent muscle fatty acid dynamics were observed, especially more strongly in females than males (Sharma et al. 2021; Sharma et al. 2022). The detailed illustration of sex-specific seasonal fatty acid dynamics, observed in *T. putitora*, is presented in Fig. 19.6.

19.12 Fatty Acid Profile of Indian Himalayan Fishes

Among the Indian cold-water fishes, information on fatty acids profile is available for *C. carpio* (collected from the Himalayan region), *O. mykiss*, *N. hexagonolepis*, *T. putitora*, *S. curvifrons*, *S. esocinus*, *S. labiatus*, *S. niger*, *S. plagiostomus*,

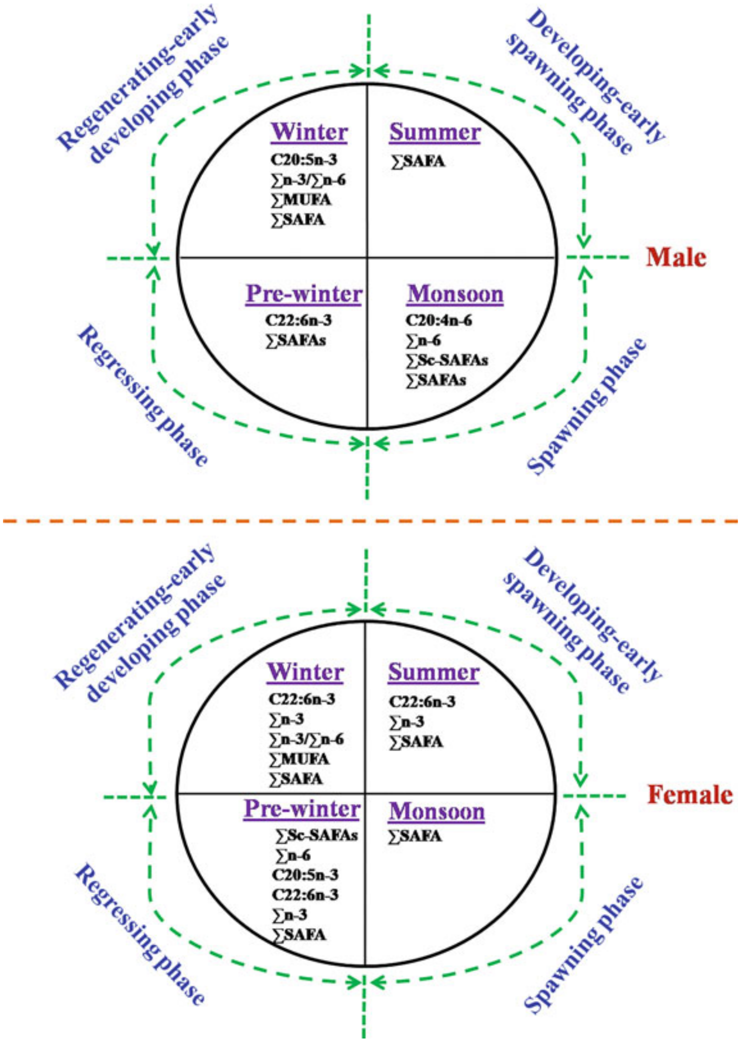

Fig. 19.6 Sex-specific seasonal dynamics of fatty acid profile in *T. putitora*

S. progastus, and *S. richardsonii* (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2016a; Sarma et al. 2013, 2022). The fatty acid compositions of cold-water fishes are summarized from these published bodies of literature and are presented in Table 19.2. Like any other fish species, C16:0 (palmitic acid) is abundant among all saturated fatty acids in all cold-water fishes. Irrespective of their habitat and physiological condition, whether they are wild-captured or farmed, male or female, etc., in almost all evaluated fishes, palmitic acid is abundant in their muscle tissue (Alasalvar et al. 2002; Andrade et al. 1995; Grigorakis et al. 2002; Jabeen and Chaudhry 2011; Sarma et al. 2013; Sharma et al. 2010; Swapna et al. 2010).

Table 19.2 Fatty acid composition (mg/100 g protein) of some Indian Himalayan cold-water fishes (captured from wild)

Fish species	C14:0	C16:0	C18:0	∑SAFAs	C16:1	C18:1	∑MUFAs	LA	AA	∑n-6	EPA	DHA	∑n-3	∑n-6/∑n-3
Cyprinus carpio	60	1050	210	1380	300	510	930	300	120	420	–	152	300	1.40
Oncorhynchus mykiss	152	836	304	1330	312	923	1330	532	76	684	82	225	532	1.29
Neolissochilus hexagonolepis	83	983	195	1462	366	360	789	251	89	340	302	210	690	0.49
Tor putitora	215	1359	413	2279	413	520	1208	318	77	417	202	116	370	1.13
Schizothorax curvifrons	886	2815	145	3885	937	675	1716	124	255	603	7	163	170	3.55
S. esocinus	479	2001	203	2708	614	879	1559	1	179	365	4	166	171	2.14
S. labiatus	303	1145	1297	3009	1010	814	1824	4	194	198	145	124	588	0.34
S. niger	749	2777	3.92	3565	930	71	1096	141	283	653	6	159	165	3.97
S. plagiostomus	283	1249	185	1745	300	558	910	115	34	255	5	56	61	4.17
S. progastus	285	1276	169	1745	373	216	606	<1	26	243	5	76	81	2.99
S. richardsonii	187	644	185	1019	526	361	918	51	19	80	236	93	398	0.20

The mean values are presented here from the different sources (Joshi 2017; Joshi et al. 2017; Sarma et al. 2013; Mohanty et al. 2016a, b) Abbreviations: *SAFAs* saturated fatty acids, *MUFAs* monounsaturated fatty acids, *LA* linoleic acid (C18:2n-6), *AA* arachidonic acid (C20:4n-6), *EPA* eicosapentaenoic acid (C20:5n-3), *DHA* docosahexaenoic acid (C22:6n-3)

Further, in these fishes, the sum of all saturated fatty acids is more than monounsaturated fatty acids; and this is common in most wild-caught freshwater fishes (Jabeen and Chaudhry 2011; Sharma et al. 2010). The proportion of PUFAs in muscle tissue, compared to the sum of all saturated or monounsaturated fatty acids, is low in most freshwater fishes (Vlieg and Body 1988; Sharma et al. 2010; Jabeen and Chaudhry 2011; Sarma et al. 2013). Similarly, in cold-water fishes as well, the sum of PUFAs is lower than saturated or monounsaturated fatty acids. Among monounsaturated fatty acids, C16:1 and C18:1 are the most abundant in their muscle lipid. The sum of all n-6 fatty acids, compared to n-3, is abundantly available in muscle lipid of *C. carpio*, *O. mykiss*, *T. putitora*, *S. curvifrons*, *S. esocinus*, and *S. niger*. Otherwise, all other species like *N. hexagonolepis*, *S. labiatus*, *S. plagiostomus*, *S. progastus*, and *S. richardsonii* are rich in n-3 PUFAs. The predominance of n-6 fatty acids over n-3 in freshwater fishes is a common phenomenon, and this is due to their natural food, in which n-6 PUFAs, especially LA, predominate over ALA (Ackman 1967). *O. mykiss*, *N. hexagonolepis*, *S. plagiostomus*, *S. labiatus*, and *S. richardsonii* are rich in n-3 LC-PUFAs such as EPA and DHA; otherwise, all the rest are rich in AA.

19.13 Importance of Dietary N-3 LC-PUFAs and Contribution Potential of Cold-Water Fishes

Fatty acids, mostly short-chain and saturated or monounsaturated, are nutrients for energy sources, through mitochondrial β-oxidation (Tocher 2015). However, the long-chain and highly unsaturated fatty acids serve as functional constituents of phospholipids, which in turn have important structural and functional roles in the cell membrane by altering the fluidity of the membrane. Membrane functionality thus influences membrane transport (exchange of nutrients, metabolites, etc.), signal transduction, enzyme function, etc. (Tocher 1995). LC-PUFAs, also serve as a precursor for synthesizing prostaglandins, leukotrienes, lipoxins, resolvins, protectins, etc. (Tocher 2010, 2015).

More importantly, DHA is involved in the development of the fetal brain, eye retina, and cognition (Birch et al. 2000). Thereby, LC-PUFAs regulate the delicate balance of lipid metabolism and favor negative fat balance by regulating the PPAR-alpha receptor-mediated pathway (FAO-WHO 2010). Dietary inclusion of n-3 LC-PUFAs lowers blood cholesterol and TAG, maintains optimum platelet function, and lowers the risk of hypertension, CVD, rheumatoid arthritis, inflammatory bowel disease, respiratory burst, atherosclerosis, arrhythmia, thrombosis, ADHD, depression, dementia, Alzheimer's disease, and colorectal, breast, and prostate cancers (Calder and Yaqoob 2012; Tocher 2015; Gil et al. 2012; Miles and Calder 2012; Cabré et al. 2012; Calder 2013; Givens et al. 2006; Harris 2004; Dangour et al. 2012; Gerber 2012).

The FAO/WHO and Indian Council of medical Research (ICMR) recommended the dietary requirements of FAs based on national survey studies, equilibrium maintenance of nutrients (balance between the tissue deposition and excretion, out

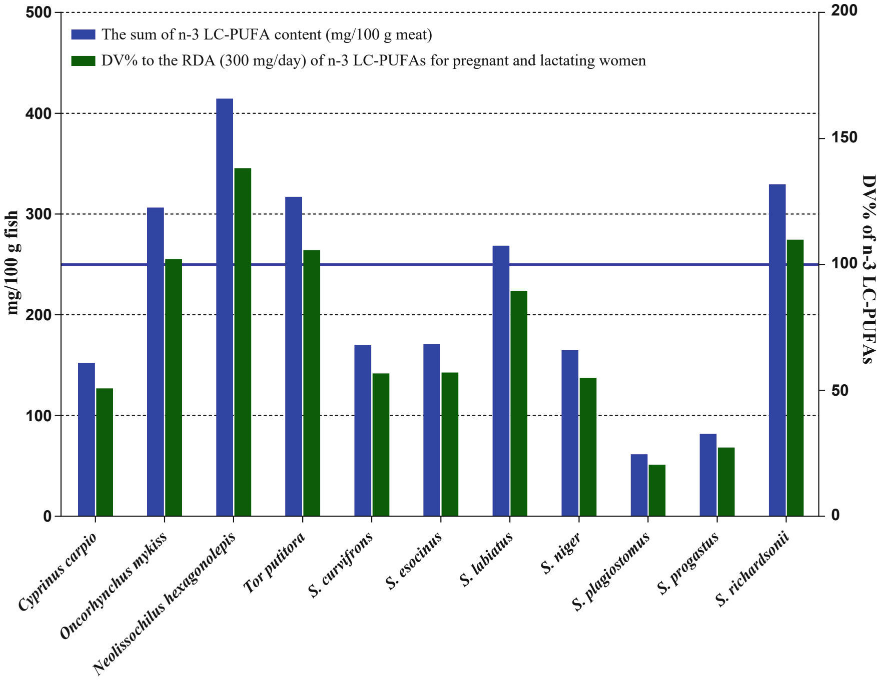

Fig. 19.7 The sum of n-3 long-chain polyunsaturated fatty acids (n-3 LC-PUFA) content (mg/100 g) of cold-water fishes from the Indian Himalaya, and their contribution potential (daily value percent; DV%) to meet the recommended dietary allowance (RDA) for pregnant and lactating women. The data are compiled from published reports (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2016a; Sarma et al. 2013, 2022)

of ingested amount), and data based on animal studies (FAO-WHO 2010; ICMR 2010). Daily intake of 100 g of *O. mykiss* or *N. hexagonolepis* or *T. putitora* or *S. richardsonii* sufficiently (more than 100%) serves the daily requirement of n-3 LC-PUFAs (Fig. 19.7). 100 g of *S. labiatus* marginally serves the daily requirement. However, to meet the daily requirement of LC-PUFAs, around 200 g of *C. carpio* or *S. curvifrons* or *S. esocinus* or *S. niger* is needed. *S. plagiostomus* and *S. progastus* have limited content of LC-PUFAs in their muscle, and they poorly serve to meet the daily requirement.

19.14 Minerals

Minerals are inorganic elements that are vital constituents of animal bodies, including fish and humans. They exist either as ions (sodium, potassium, chlorine, etc.) or as complex molecules (as a constituent of metalloprotein like iron in hemoglobin and myoglobin, calcium-phosphate complexes of the bone, etc.). The inclusion of minerals in the diet is essential to maintain their required levels in the body for normal body function, growth, and development and to replace wear and tear due to aging (NRC 1989). Some are required in higher concentrations in the diet and are called macrominerals, while others are required in lower concentrations and are called microminerals. Dietary macrominerals are sodium, potassium, calcium, magnesium, and phosphorus, while microminerals are iron, copper, zinc, manganese, and selenium (Mohanty et al. 2016b). Microminerals, on the other hand, act as components of hormones, enzymes, vitamins, or other vital biochemical compounds and help in maintaining the normal physiological functioning of a human body by regulating various biochemical processes (NRC 1989).

19.15 Fish as a Source of Dietary Minerals

Fish, in general, contains a fair combination of dietary minerals such as calcium, phosphorus, and microminerals. Compared to the mineral content of the wild-caught marine, freshwater, and cold-water fish, the composition is more or less similar. However, there are some inter-species variations in the composition of some particular minerals (Bogard et al. 2015; Mohanty et al. 2016b). For example, the calcium content in SIFs such as *Gudusia chapra* and *Xenentodon cancila* is very high (3000–5000 mg/100 g), but the same is comparatively low (120 mg/100 g) in *Tenualosa ilisha* (Mohanty et al. 2016b). The composition of some minerals (not all) in fish muscle, like other nutrients, varies with season. However, the reports on seasonal variability of mineral contents of fishes are very few to date. The minerals which show their seasonality in fish muscle include iron, manganese (summer > spring > autumn > winter), and zinc (autumn > summer > spring > winter) (Mendil et al. 2010). The exact reason behind this phenomenon is yet to be found. The seasonal change in the composition of macrominerals is not reported in fish.

19.15.1 Mineral Composition of Cold-Water Fishes of Indian Himalaya

Among the Indian cold-water fishes, information on fatty acids profile is available for *C. carpio* (collected from the Himalayan region), *O. mykiss*, *N. hexagonolepis*, *T. putitora*, *S. curvifrons*, *S. esocinus*, *S. labiatus*, *S. niger*, *S. plagiostomus*, *S. progastus*, and *S. richardsonii* (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2016b; Sarma et al. 2013; Sarma et al. 2022). Mineral compositions of cold-water fishes are summarized from these published sources of literature (Table 19.3). Among macrominerals, sodium content is high in *C. carpio* (268 mg/100 g) and *S. richardsonii* (260 mg/100 g) and low in *S. labiatus* (80 mg/100 g) and *S. progastus* (70 mg/100 g); potassium content is very high (400–1200 mg/100 g) compared to *L. rohita* and *C. catla* (except *T. putitora*). Similarly, calcium and phosphorus are also high in all cold-water fishes. Among microminerals, iron and zinc contents are comparatively high (than *L. rohita* and *C. catla*) in all *Schizothorax* spp., except in

Table 19.3 Mineral composition (mg/100 g) of some common tropical edible carps and cold-water fishes from Indian Himalaya

	Macrominerals (mg/100 g)					Microminerals (mg/100 g)			
Minerals	Na	K	Ca	Mg	P	Fe	Cu	Zn	Mn
Labeo rohita	202	268	206	–	125	2.20	–	1.90	0.40
Catla catla	198	284	161	–	147	1.60	–	1.30	0.30
Cyprinus carpio	268	1126	409	–	–	0.50	–	3.20	0.30
Oncorhynchus mykiss	215	1217	419	–	–	1.30	–	1.30	0.20
Neolissochilus hexagonolepis	214	575	1175	–	–	20	–	1.90	0.20
Tor putitora	173	1016	116	–	–	0.90	–	1.30	0.20
Schizothorax curvifrons	150	460	430	90	640	11.82	0.72	6.45	0.43
S. esocinus	140	480	410	70	680	11.54	1.24	4.62	1.43
S. labiatus	80	1090	440	110	890	7.02	1.17	6.62	0.74
S. niger	140	580	430	100	670	11.45	1.73	6.03	1.62
S. plagiostomus	180	700	360	150	830	11.83	1.14	2.64	1.02
S. progastus	70	450	350	80	580	12.59	1.81	5.4	1.26
S. richardsonii	260	610	300	90	630	12.02	1.52	5.62	1.32

The mean values of the mineral (sodium Na, potassium K, calcium Ca, magnesium Mg, phosphorus P, iron Fe, copper Cu, zinc Zn, and manganese Mn) contents are presented here from different sources (Joshi 2017; Joshi et al. 2017; Sarma et al. 2013; Mohanty et al. 2016b)

the case of zinc content in *S. plagiostomus*. Similarly, manganese content is also high in all *Schizothorax* spp. (>1 mg/100 g fish except in *S. labiatus*).

19.15.2 Dietary Mineral Requirements and Dietary Contribution Potential

Assessment of mineral requirements in the human diet is based on several approaches such as mineral balance studies (for calcium, phosphorus, magnesium, zinc, and other microminerals), accretion and mineralization dynamics (for calcium and phosphorus), clinical trials using dose-response studies (for calcium and phosphorus), turnover studies (for magnesium and zinc), and basal loss (for iron) (ICMR 2010).

Mineral requirements vary for different age groups, sexes, and physiological and pathological conditions of the subject. The RDA values given by the ICMR (2010) for the Indian context are valuable for deducing the species-specific mineral contribution potentials of the different food item, including fish. The dietary mineral contribution potentials of cold-water fishes of Indian Himalaya are presented in Fig. 19.8. Dietary sodium, potassium, and magnesium contribution potential of all cold-water fishes are negligible as those of *L. rohita* and *C. catla*. However, the dietary calcium and phosphorus contribution potential of cold-water fishes are high,

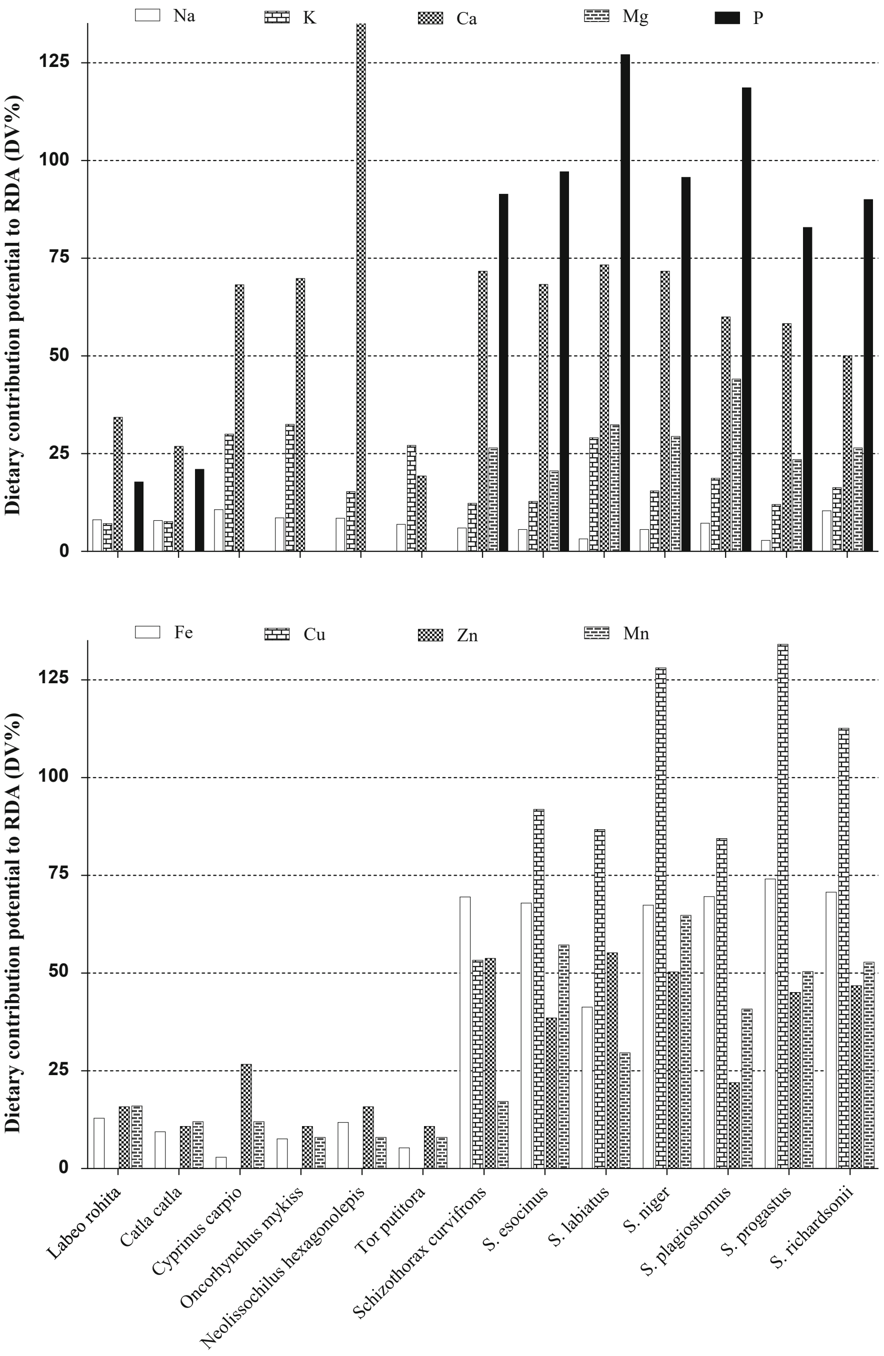

Fig. 19.8 The dietary contribution potential (daily value percent; DV%) of macrominerals and microminerals to meet the recommended dietary allowance (RDA) of cold-water fishes, along with DV% of *L. rohita* and *C. catla*. The data are compiled from published reports (Joshi 2017; Joshi et al. 2017; Mohanty et al. 2016b; Sarma et al. 2013, 2022). The RDA of sodium (Na), potassium

compared to *L. rohita* and *C. catla*. More specifically, calcium contribution potential of *N. hexagonolepis* and phosphorous contribution potential of *S. labiatus* and *S. plagiostomus* are more than 100%.

The dietary micromineral contribution potential of seven species of *Schizothorax* are significantly higher than those of *L. rohita*, *C. catla*, *C. carpio*, *O. mykiss*, *N. hexagonolepis*, and *T. putitora* (Fig. 19.8). Dietary copper contribution potentials of *S. niger*, *S. progastus*, and *S. richardsonii* are well above 100% per 100 g of fish. Those for the rest of other *Schizothorax* spp. are between 50 and 100%.

19.16 Conclusion

Consumption of fish may provide both nutrients and nutraceuticals to fight against NDDs and LDs. Fish has an important place in human nutrition for its unique n-3 LC-PUFAs content, abundant bioavailable micronutrients, and highly digestible protein. Compilation of information on the nutrient composition of cold-water fishes revealed that they are rich in nutrients with ample potential to contribute to the daily nutrient requirement of humans of all ages, sex, and physiological condition. Especially, the micronutrient contents of almost all cold-water fishes are superior to that of *L. rohita* and *C. catla*. Species like *N. hexagonolepis*, *S. labiatus*, *C. latius*, and *G. Lamta* are very rich in protein. *S. labiatus*, *S. richardsonii*, *S. esocinus*, and *S. progastus* are rich in most of the essential amino acids. *S. curvifrons*, *S. labiatus*, *S. niger*, *O. mykiss*, *T. putitora*, *S. esocinus*, and *B. bendelisis* are specifically rich in oil.

The n-3 LC-PUFAs, on the other hand, are abundantly available in *O. mykiss*, *N. hexagonolepis*, *S. richardsonii*, *T. putitora*, *S. curvifrons*, and *S. labiatus*. Fishes rich in minerals are *O. mykiss*, *T. putitora*, and all species of *Schizothorax* spp. (Fig. 19.9). The cold-water fishes of the Indian Himalaya are rich in one or the other nutrients and the corresponding dietary contribution potential. This compiled nutritional information of all cold-water fishes of the Indian Himalayan region may prove valuable to nutritional scientists for further research on fish processing, product development, and value addition.

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Fig. 19.8 (continued) (K), calcium (Ca), magnesium (Mg), and phosphorus (P) are, respectively, 2500, 3750, 600, 340, and 700 mg/day. The RDA of iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) are, respectively, 17, 1.35, 12, and 2.5 mg/day

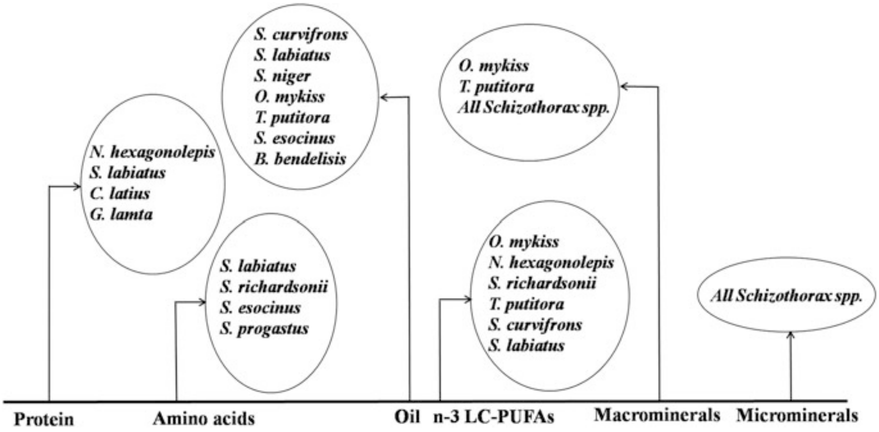

Fig. 19.9 Species-specific nutrient abundance in cold-water fishes of the Indian Himalaya

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